Alexandria Engineering Journal (2022) 61, 12623–12634

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

Experimental investigation to thermal performance of different photo voltaic modules for efficient system design

Saad Ur Rehman [a], M. Farooq [a,*], Adnan Qamar [a], M. Usman [a], Gulzar Ahmad [a,b], M. Sultan [c], M. Wajid Saleem [d], Ijaz Hussain [e], M. Imran [b,*], Qasim Ali [f], M. Yasar Javaid [g], Farrukh A. Siddiqui [h,*]

[a] *Department of Mechanical Engineering, University of Engineering & Technology (UET) Lahore - 54800, Pakistan*
[b] *College of Engineering and Physical Sciences, Department of Mechanical, Biomedical and Design Engineering, Aston University, B4 7ET Birmingham, UK*
[c] *Department of Agricultural Engineering, Bahauddin Zakariya University, Bosan Road, Multan, 60800, Pakistan*
[d] *Department of Mechanical and Mechatronics Engineering, College of Engineering, Dhofar University Salalah, Sultanate of Oman*
[e] *Center for Refining & Advanced Chemicals, King Fahd University of Petroleum & Minerals, Dhahran, 31261, Saudi Arabia*
[f] *Department of Mechanical Engineering, College of Engineering and Technology, University of Sargodha, 40100, Pakistan*
[g] *Department of Mechanical Engineering and Technology, Government College University Faisalabad, Faisalabad, Pakistan*
[h] *Department of Mechanical Engineering, Bahauddi n Zakariya University, Bosan Road, Multan, 60800, Pakistan*

Received 3 February 2022; revised 26 March 2022; accepted 18 June 2022

KEYWORDS

Renewable energy;
Photovoltaic modules;
Thermal performance;
Solar irradiance;
Photovoltaic module efficiency;
Performance ratio

Abstract Due to rapid industrialization, and depletion of fossil fuels, alternative renewable resources are mandatory, where solar thermal energy is one of the promising alternate. In this study, an experimental investigation was conducted to analyze the thermal performance of different photovoltaic-modules under varying climate conditions. These include thin plate Copper indium diselenide, mono-crystalline silicon, micro crystalline silicone, amorphous silicon and poly-crystalline silicon. The analysis was concentrated on the evaluation of module efficiency, solar irradiance absorption rate, maximum power output, performance ratio, normalized power output efficiency and temperature effect on each module at real operational outdoor conditions. Mono-crystalline silicon module showed high average efficiency of 20.8% and average performance ratio 1.21 compared to the other PV modules. It was observed that all types of modules have higher average temperature in summer season and showed low performance ratio and low module efficiency as compared to winter season. Average normalized power out of mono-crystalline silicon 56.2% more efficient than the other modules. The increased thermal performance of mono-crystalline silicon was related with its high absorption rate and high conduction rate. Thus, mono-crystalline silicon PV

* Corresponding authors.
E-mail addresses: engr.farooq@uet.edu.pk (M. Farooq), m.imran12@aston.ac.uk (M. Imran), farrukh.siddiqui@bzu.edu.pk (F.A. Siddiqui).
Peer review under responsibility of Faculty of Engineering, Alexandria University.

https://doi.org/10.1016/j.aej.2022.06.037
1110-0168

Nomenclature

AM	Air mass	STC	Standard test condition
Aa	Active area of module (m2)	Vmax	Maximum voltage (V)
a-Si	Amorphous silicon module	Voc	Open circuit voltage (V)
c-Si	Monocrystalline silicon module	ϕ	Angle of inclination
CIS	Copper indium diselenide	ηp	Normalized power output efficiency
I	Solar irradiance (W/m2)	ηm	Module efficiency
ED	Direct solar irradiance (W/m2)	I-Vcurve	Current-Voltage characteristics curve
EH	Solar irradiance at horizontal surface (W/m2)	W	Watt
Imax	Maximum current (A)	Wh	Watt hour
Isc	Short circuit current (A)	V	Volt
PR	Performance ratio	A	Ampere
Pmax	Maximum power (W)	W/m^2	Watt per meter square
Pmea	Measured power output (W)	KWh/m^2	Kilowatt hour per meter square
PV	Photovoltaic	°F	Degree Fahrenheit
p-Si	Polycrystalline silicon module	°C	Degree Celsius

module is the best potential candidate for solar capturing technique to be utilize in diverse solar thermal energy applications.

1. Introduction

Every year a huge amount of revenue is spent to buy crude oil to fulfill energy demand that put a heavy burden on the economy of the any country. Abrupt increase of energy demand and depleting conventional fossil fuels has drawn attention of investors, direct buyer as well as the researcher to shift on renewable energy and start the projects to utilize hydel power, biomass gas, ocean tidal wave, solar power energy and wind energy. This will not only fulfil the current needs of the society but will also minimize the environmental contamination caused by conventional energy sources, i.e. crude oil, natural gas and coal [1–8]. In the present era, the energy shortage is the most common and important issue. Due to unbalance in demand and supply, energy deficit has been increasing [9–15], leading towards the economic shutdown gradually. At the moment the setup electric power production is approximate 23,500 megawatt (MW) and energy shortfall lies in between 3000 MW and 6000 MW in peak hours [16]. During summer season energy deficit reaches to its maximum level which leads the country under severe load shedding of several hours, in industrial, metropolitan and remote places [17–21]. Approximate 175,800 Giga watts (GW) power was evaluated over the total area under the 5.3 kWh/m^2 mean daily solar irradiances, which is equivalent to the 19 MJ/m^2 per year that show the strong potential of solar energy in this region consuming only 0.001% of this total solar energy to produce electric power which is equivalent to 16–18 Giga watt (GW) [16].

Renewable energy resources are globally used, however solar energy has its own significance and a fraction of energy coming from sun could solve all energy problems of the country. Solar energy is very fair and clean which causes no pollution. Now it is time to invest in solar power projects that is crucial and is the need of the hour [22–26].

Performance analysis and the variations estimated in the measured data are crucial to know for the prediction of best PV module in any particular weather conditions [27–30]. Different research scholars have evaluated the PV performance in different climates. Conventional energy sources are reducing, and energy demand is still increasing day by day, which created a very serious energy short fall in the country. The country has become distinguished among the other countries across the globe due to the availability of long sunshine hours suitable for photovoltaic implementation for power production. It has the potential to fulfil the energy needs of domestic, rural, industrial and irrigation sectors [31–37].

The aim of this study is to focus on the outdoor characterization of three commercially available PV modules in a tropical climate and to examine the performance ratio (PR) with of different performance characteristics. Each module was tested with the IV curves of Copper Indium Gallium di Selenide (CIGS) PV modules, c-Si, and p-Si modules by availing the facility of monitoring system under real time outdoor conditions. The data was collected hourly between 9 am to 5 pm for alternative days of all the months of year. The solar irradiance was recorded after every 10 min that represent 28,000 IV curves of data set for 240 points each. To attain this objective, study is established to determine the module efficiency, performance ratio, power output and temperature effect on the performance of commercially available PV modules. This paper also presented PV system designers on the variation of these coefficients in the field and the fill factor with combination of irradiance and temperature. In general perspective, the wafer technologies performs better than the thin film technology, but on the other hand thin-film technology was found to be degradation [38].

Investigation and experimental study were performed in Malaysia region for the interpretation of the efficiency of four certain types of selected solar panels which belonging to copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, crystalline silicon module with laser grooved buried contact, and amorphous silicon (a-Si) in outdoor weather conditions. This study defined that behavior of poly and mono-crystalline performed with high efficiency at high degree of temperature and amorphous silicon produced well results of efficiency in partially sunny and cloudy weather [39]. Experimental study was conducted for more than a whole year in the moderate and less harsh temperature climate region of Perth, located in continent of western Australia, Measurements made significant difference among the selected PV modules technology Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, crystalline silicon module with laser grooved buried contact, amorphous silicon (a-Si) and measurements result showed that triple junction a-Si generate 14–15% more power in summer season under diffuse sun irradiance and 8 percent in cool winter season than other modules used in this study [40]. Experimental study was carried out for the winter season in the climate of Taxila. Performance ratio (ṔR) for selected PV modules (mono-crystalline, poly-crystalline and amorphous silicon) was calculated and the results concluded that mono-crystalline module produced 13 percent efficiency (ῆ) in partially sunny and cloudy weather. Amorphous silicon module generates 1.03 mean performance ratio (ṔR) which was significantly more than other modules under the same environment factors where experiment was performed. Furthermore, Module efficiency (ῆ) and performance ratio was declined when temperature of the module gradually increase [41].

Temperature is a cognitive factor that tend to have an effect on the resultant output of PV modules [42–48]. The temperature increases on the surface of panel effects its performance and thermal properties. This paper examines the effect of heat on the parameters linked with PV power, output performance and efficiency. Photovoltaic modules are unique to handle the global energy crisis. High operating temperature effect on each module can be evaluated at real operational outdoor conditions by availing the facility of monitoring system. Efficient PV module cooling technique have to be used for this purpose to improve system performance. The most common processes are heat pipe cooling,forced, hydraulic cooling, thermoelectric cooling, natural air cooling and cooling with PCM heat pipe cooling [49].

Different researchers have observed that intense range of temperatures exert an influence on the results of PV panel system. The study of different researchers describes the methodology, experimental setup and procedure to evaluate the module electrical and thermal parameters at both standard test conditions and outdoor conditions. PV module thermo-grapy examined before the production of PV panels showed that calculated values remain within the manufacturer's purposed values [50–52]. Experimental study conducted for two years in the tropical region of Japan. Investigation showed that seasonal variation put a vigorous influence on the efficiency of photovoltaic system, by the source of this study amorphous silicon module gave well results of output power (P) and efficiency (ῆ) than polycrystalline silicon in summer [53].Same research study was conducted for whole year in the cool region of Norway. This study monitored the performance of solar panels which had different type of material and easily available in market. It showed that mono-crystalline exhibit much more well performance outcome than poly-crystalline and amorphous silicon modules [54].

The analysis of soil accumulates which change the efficiency of the solar PV module. For this purpose, 70 days' experiments were performed during outdoor condition. The results revealed that the output performance is reduced to 22 percent.After a continuous ten weeks of dust assertion on PV module, mass to volume ratio of dust on the surface from 0.01 g/m^2 at the beginning but it was gradually changed to 6 g/m^2 at the last day of this experimental study [55]. The transmission coefficient and energy conservation performance were reduced caused by dust assertion on the exterior upper layer of PV system [41,51,56–61]. The rate of reduction in the output efficiency of a crystalline PV system is directly corresponding to quantity of dust assertion on the surface, is equal to 25% per micrometer. It is very crucial to understand that the environmental conditions highly influence the behavior of PV module efficiency [62]. Photo degradation is the process in which the efficiency and the performance of amorphous silicon tend to show reduction in photoconductivity of photovoltaic material when it is exposed to light, this is also called light induced degradation (LID) [63]. Annealing is another process in which temperature that is greater than 150 is involved to degradation of PV modules silicon modules [64]. Different PV module evaluated in the tropical climate region of Indonesia and compared the performance of three certain type of PV modules in a moderate open-air weather. Module performance ratio, efficiency and normalized energy yields examined thoroughly of every module and investigate the thermal and solar irradiances effect. Mono-crystalline showed healthier results of module output efficiency and also good source of power production at moderate outdoor condition. Module efficiency and performance ratio was declined when temperature of the module gradually increase [65].

This research work consists of experimental investigation, evaluation and analyses for the thermal performance of different PV module for efficient system design under varying weather conditions. After every 20 min, approximately 30% solar irradiance reaches the earth which is enough to meet the energy demands of the global community. However, making efficient use of solar energy is not an easy task. This way allowed the maximum capturing of solar irradiance [66]. The data was collected hourly from 9 am to 5 pm after every 30 s for alternative days of all the months of year and sometime experiment had to stop due to rainy and stormy weather. In this study solar radiation values calculated through pyranometer for each PV modules. The solar irradiance was recorded after every 30 s. K-type thermocouples were installed at the central cell of each PV module to examine the overall module temperature. All the measured parametric values were recorded through data monitoring system. The data was collected for varying conditions including sunny, partially cloudy and cloudy days. PV modules used in this study expressed different behavior on different climate conditions. To attain this objective, a comparative study is established between module efficiency, performance ratio, power output and temperature effect to calculate the performance of commercially Photovoltaic modules like thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon for complete year.

2. Material and method

2.1. Experimental setup and data collection

Photovoltaic module of five dissimilar materials (thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon) were analyzed in this study. The experimental setup consists of PV modules, a variable load resister, digital pyranometer, ammeter and voltmeter, data logger for data mongering system and. K-type thermocouples (OEM WRR2-130) to calculate the average temperature of PV modules. A clarified form of experimental setup is shown in Fig. 1. PV modules (Canadian solar system,) were used to capture the solar radiations from natural sun. Ammeter (Fluke 77-IV) having DC current range from 0.001 A to 10 A with direct current accuracy of 1.0% +3 and voltmeter (Fluke 87-V) with voltage range from 0.001 V to 1000 V and accuracy of 0.09% +2.34 were used to compute the photovoltaic current and voltage respectively. A variable load resister (3250 VRL) was used as a series resistance or potentiometer with bearing current up to 5 A. Five thermocouples were installed at the back of five dissimilar material PV modules to take the average temperature. Ambient temperature was also computed through the sixth k-type thermocouple. Solar irradiance values were recorded though a pyranometer (SR30-D1), while the rest of data was executed by the data acquisition system.

The output efficiency of different photovoltaic modules strongly depends on perfect orientation, positioning and tilt angle of photovoltaic modules. The required tilt angle of photovoltaic modules is different for different positions and seasonal conditions. For maximum output power, a large tilt angle is required in winter season and comparative small tilt angle in summer. In the existing literatures many researchers have reported that the tilt angle of a fixed PV module is equal to the latitude angle of that place. If adjustment of PV module is needed twice in a year (summer winter and seasons), then angle of inclination or tilt angle was adjusted according to well-known rule as presented in equation (1) and (2) [41,51,67].

$$\text{Angleofinclination}\acute{E}\text{=Latitude} - 15^{\circ}(\text{forsummer}) \quad (1)$$

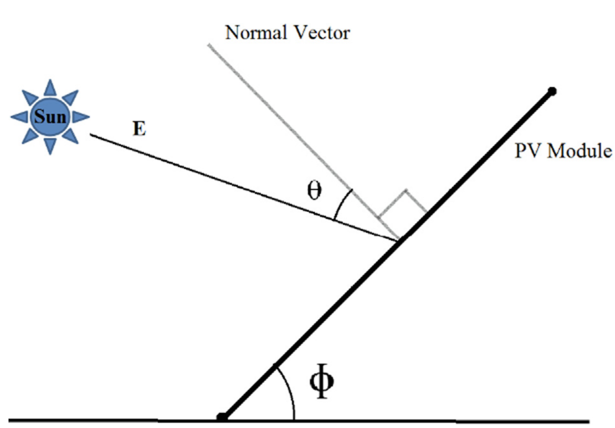

Fig. 1 Positioning of PV module on tilt angle.

$$\text{Angleofinclination}\acute{E}\text{=Latitude} + 15^{\circ}(\text{forwinter}) \quad (2)$$

The latitude of experimental setup location was 31.69°. Using equation **(1)** and equation **(2)** tilt angle of 16.69° and 46.69° were observed during summer and winter respectively. It has been seen that tilt angle mostly depends upon the time of year. In the Fig. 2, the PV module is directly perpendicular to the solar irradiance angle (θ). Increase in the output power of module is achieved with decrease in the angle (θ) and modules have maximum power when i.e. sun is at normal to the face of PV module. E represents the solar irradiance reaching to the module surface.

Experimentation was executed in the outdoor weather conditions. The modules were placed at the roof top at a fixed tilt angle of 16.69° for summer season and 46.69° for winter season with horizontal plane as per latitude of 31.69° [41,51]. The characteristic parameters of PV modules were obtained from I to V curve, drawn by using variable resistance and multimeters, the data acquisition system calculated module power output from the module voltage and module current measurements that are made each second. The performance related all parameters are calculated every second by using equations on the site where setup was installed at required tilt angle and then averaged over hourly intervals**.**

2.2. PV modules rated values and parameters analysis

The study of different researchers describes the methodology, experimental setup and procedure to evaluate the module electrical and thermal parameters at both standard test conditions and outdoor conditions. The performance related parameters are calculated using equations (3)-(7) [40,51].

Horizontal Solar Irradiance.

$$E_H = E_D \cos(\theta) \quad (3)$$

Power Output.

$$\text{Pmax} = \text{Vmax} \times \text{Imax} \quad (4)$$

Normalized Power out put.

$$\eta p = \left(\frac{\text{Pmax}}{\text{Pmax(STC)}}\right)\text{x100} \quad (5)$$

Module Efficiency.

$$\eta m = \left(\frac{\text{Pmax}}{\text{IxAa}}\right)\text{x100} \quad (6)$$

Performance Ratio.

$$\text{PR} = (\text{Pmax}/\text{Pmax(STC)})/((I/1000)) \quad (7)$$

The typical conditions at which different PV modules are rated on bases of different variables is called standard test conditions that are shown in Table 1. Actually, standard test conditions (STC) express the industry-wide standard values of performance of different PV modules and indicate an irradiance of 1000 W/m^2 and cell temperature of 25 °C at room with an air mass (AM 1. 5). Natural sun is operated under such conditions that it produces natural light source to test thermal performance of different PV modules. Generally, manufacturer of PV panel proposed the standard test conditions (STC) values for different PV modules. The information given in Table 1. at standard test conditions (STC) includes maximum photo-

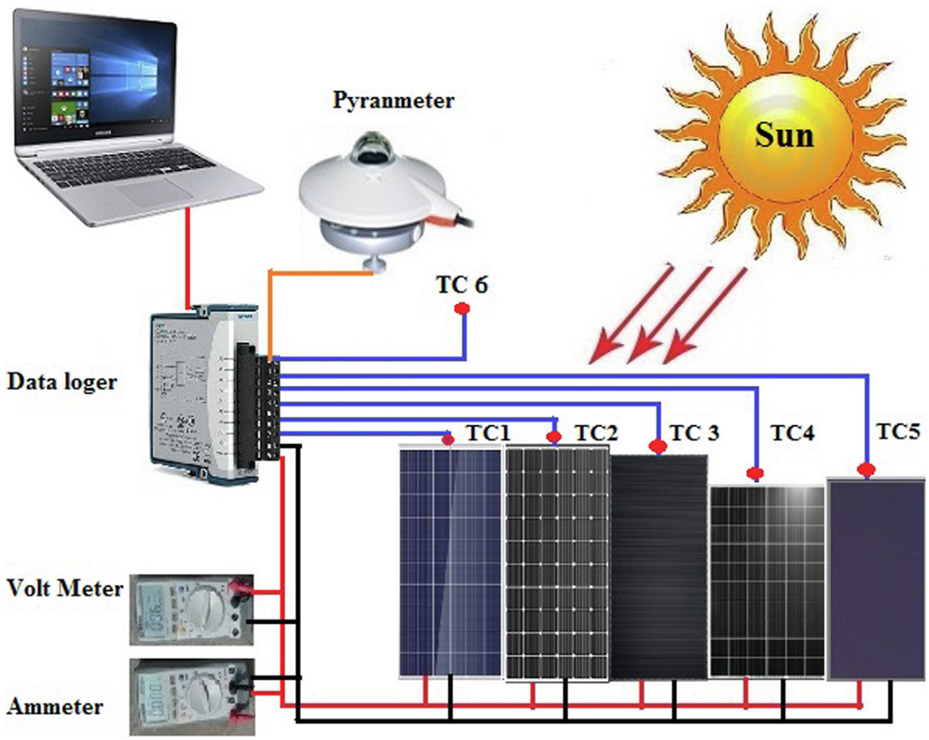

Fig. 2 Experimental setup of solar PV system.

Table 1 Physical dimension and specification of different photovoltaic modules.

PV Modules	c-Si	p-Si	(***CuInSn***$_2$)	Micro-Si	a-Si
Module Dimensions					
Module Dimensions (mm^2)	1480 × 680	1480 × 680	890 × 480	810 × 720	1250 × 640
Cell Dimensions (mm^2)	155 × 155	165 × 165	860 × 450	780 × 680	1220 × 610
No. of cells in series	4 × 9	4 × 9	1	1	1
Cell area (m^2)	0.864	0.924	0.384	0.54	0.7442
Rated Values					
Maximum Power, Pmax (W)	150	150	40	40	40
Maximum Voltage, Vmax (V)	17.9	18	16	45.81	47.04
Maximum Current, Imax (A)	8.38	8.29	2.40	0.87	0.82
Short Circuit Current, Isc (A)	8.92	8.91	2.65	0.95	0.90
Open Circuit Voltage,Voc (V)	22.2	22.1	23.18	52.4	54.7

voltaic power output, maximum photovoltaic current, open circuit voltage, short circuit current and maximum voltage of photovoltaic panel.

3. Results and discussion

3.1. Solar irradiance measurement analysis

Finest way is to use solar energy with assistance of PV modules, which directly capture and convert solar radiations into the direct current using equation (3) that is resulted to produce power that is solution to fulfill energy demands. As shown in Figs. 3a and 3b, the average value of solar irradiance throughout the year were evaluated with the help of pyranometer. The intensity of solar heat decreases with the reduction in solar irradiance. A maximum absorption rate was computed in the month of June (664.59 W/m^2) was due to more sun shine hours and high solar intensity, December showed (240.94 W/m^2) lowest solar irradiance value due to fogy and moisture conditions of the weather that decreased the solar absorption intensity as compared with others months.

In Fig. 3c. solar irradiance value for month of Jun was expressed from 9:00 am to 5:00 pm. Highest average irradiances value 834.23 (W/m^2) was observed at 1:00 pm and lowest average solar irradiance 360.19 W/m^2 was examined at 5:00 pm. Solar irradiance intensity from morning 9:00 am to 12:00 pm was increased to reach it maximum peak value at

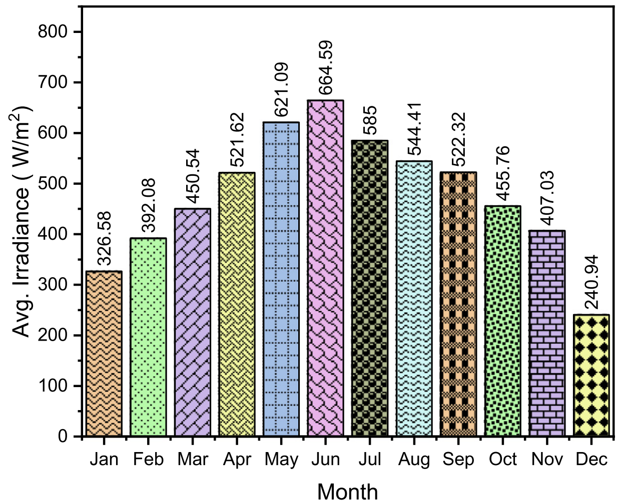

Fig. 3a Solar Irradiance average values for twelve months of whole year.

1:00 pm but afterward its valued was reduced (after noon 2:00 pm to 5:00 pm). The greater and lower average value of solar irradiance in June was because of high and low solar intensity during different hours of the days.

3.2. Maximum power output analysis

Maximum power output is the major key parameter to compute the thermal performance of photovoltaic modules at different outdoor conditions under natural sun. Usually current–voltage curve (I-V curve) is used to express the value of maximum power output. Here, in this research study, high power variable resistance is used for calculating maximum power point by using equation (4) which show the main characteristic of the power output. A high-power variable resistance was used to fluctuate the voltage and current values in this work. When resistance value is zero, then the value of voltage in the circuit is zero and maximum value of current flows in the circuit. The maximum current, where value of voltage is

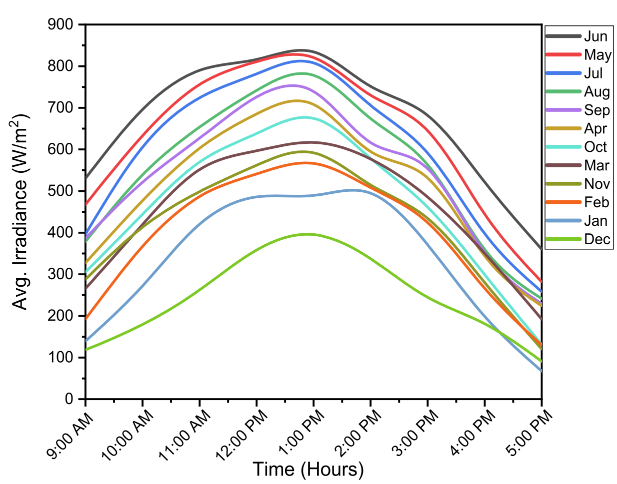

Fig. 3b Average Irradiance values for whole year from 9:00 AM to 5:00 PM.

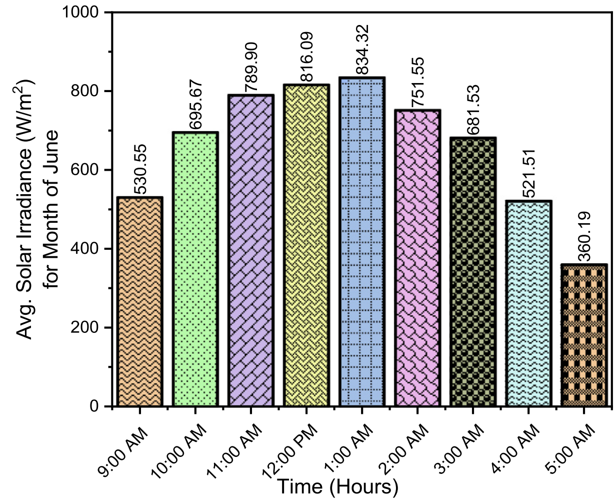

Fig. 3c Average Irradiance values for the month of June from 9:00 AM to 5:00 PM.

recorded zero called "short circuit current". In contrast, when value of resistance progressively increasing, current decreases and the voltage increases accordingly. At highest value of resistance, current becomes zero and voltage reaches the maximum value, called "open circuit voltage". In order to evaluate this variation in the highest power output value, an experimental setup of different modules was installed on a fixed structure under real outdoors conditions.

Figs. 4a and 4b showed the maximum power output value of different PV modules (thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon) were evaluated for the whole year. It is examined that the maximum output power of different types of PV modules are directly linked with values of current and voltage that is strongly dependent on the solar irradiance rate. Fig. 4a represents the relation between average maximum power outputs of five different PV modules and

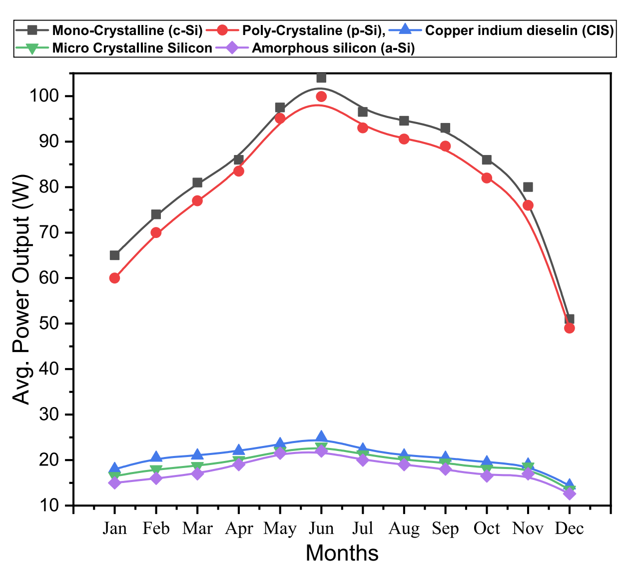

Fig. 4a Average maximum output power trend of different PV modules for twelve months.

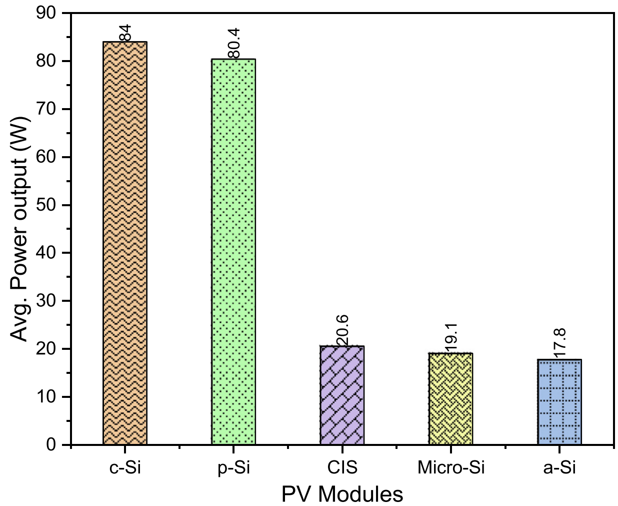

Fig. 4b Average values of maximum power output for different PV modules for whole year.

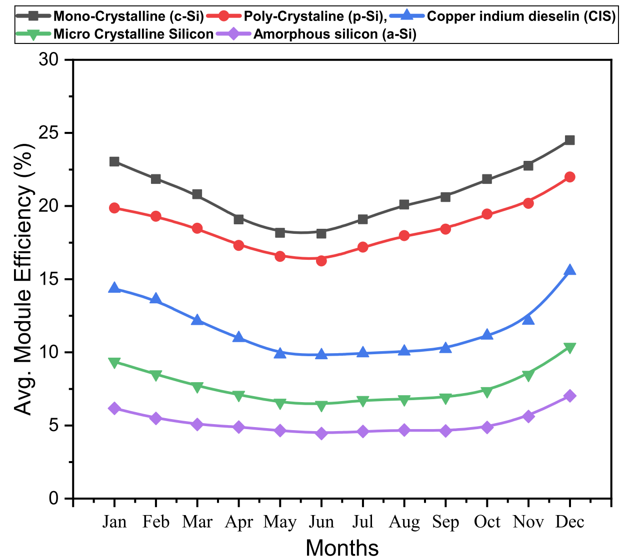

Fig. 5a Average module efficiency of different PV modules for whole year.

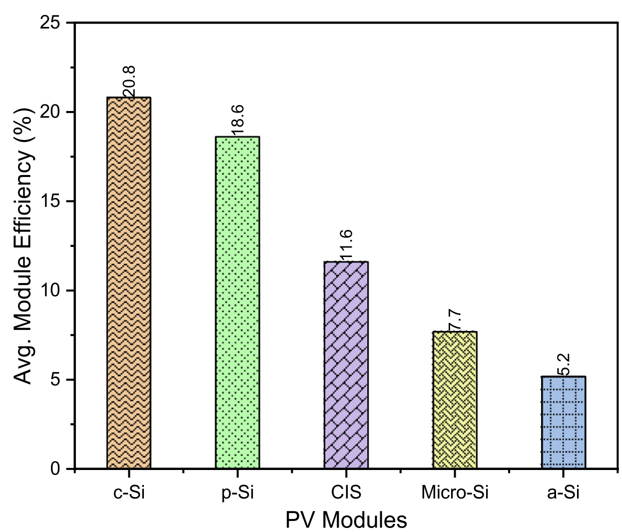

Fig. 5b Average values of module efficiencies for different PV modules for whole year.

solar irradiation of all the months of year. All five modules have liner trend in start with the solar irradiance as the solar irradiance increases, maximum power output of all module showed incremental trend but it declined in the evening as solar irradiance decreased. That mean PV modules produced maximum power at the maximum solar irradiance due to the high solar energy absorption and high thermal conductivity. The maximum power output values of (thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon) were observed 20.6 W, 80.4 W, 84 W, 19.1 W and 17.8 W correspondingly in overall year. Mono-crystalline silicon has the highest value of maximum power output in month of June relative to other PV modules shown in Fig. 4b.

3.3. Module efficiency analysis

The module efficiency is computed through the formula and is the ratio of maximum output power of module to the total incident solar radiation. This total incident is multiply by active area of the module [16,19].

Figs. 5a and 5b represented, module efficiency value of different PV modules (thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon) for whole year. It is examined that module efficiency of different types of PV modules are directly linked with maximum power output and inversely related with module temperature [43,68–70].

Fig. 5a showed that different type of PV modules has liner decreasing trend in the beginning with the increase in solar irradiance, PV module efficiency showed decrement trend then incremental trend in the evening as soar irradiance decreased. PV module efficiency of (thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon) were observed 11.6 %,18.6 %, 20.8 %, 7.7 % and 5.2 % respectively in overall year is shown in Fig. 5b. Mono-crystalline silicon exhibit the highest efficiency as compared to other PV modules due to quality of high solar absorptivity property, high temperature gaining property and higher value of thermal conductivity.

3.4. Performance ratio analysis

Performance ratio is used conventionally to.

sexpress the relation between maximum output power of the photovoltaic modules calculated at outdoor condition relative to product of Irradiance and maximum out power of the photovoltaic modules computed at standard test conditions (STC). It can calculate the performance efficiency of any type of module using equation (7) that can be proved more helpful to finding [19].

Performance ratio showed decrement trend with the increase of module temperature that can be resulted as degradation of PV module in last [69,71–73], it can be clearly seen in Fig. 6a. It can be seen that performance ratio of thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon 1.09, 1.16, 1.21, 1.03, 0.96 respectively in Fig. 6b. Comparing all the PV modules used, mono-crystalline silicon PV module has the maximum performance ratio (PR) at different test conditions.

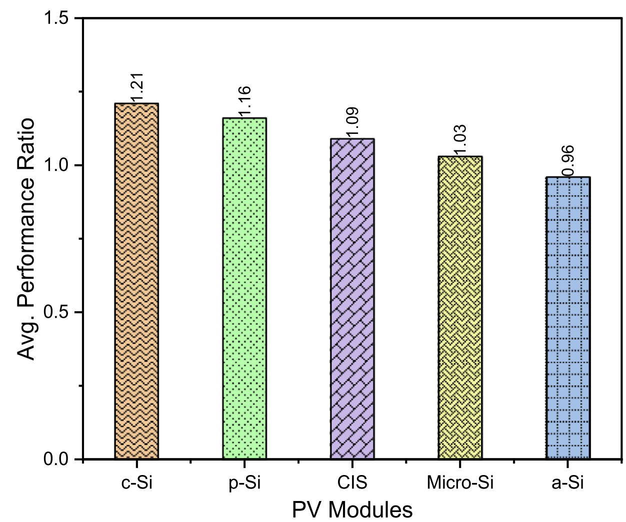

Fig. 6b Average values of performance ratio for different PV modules for whole year.

3.5. Module temperature analysis

Fig. 7a expressed the average value of temperature for whole year computed through K-type thermocouple (TC_6). A maximum average value of temperature was examined at the month of June because of high solar intensity and more sun shine hours and, December showed lowest value due to fogy and moisture conditions of the weather. Fig. 7b **s**hows the temperature variations of five types of PV modules (thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon) under natural sunshine. Comparing value of average temperatures of all the PV modules used in this work, mono-crystalline silicon PV module has the highest average value of temperature among all in the month of June due to highest solar absorption than others PV modules. When it comes to compare with all the photovoltaic modules temperature, ambient temperature is lower than module temperature in whole year. The module temperature reduction is also observed due to sudden decrease of solar irradiance. Furthermore, temperature shows direct proportionality with the solar irradiance [74–76]. Sometime solar cell exhibited greater temperature value than ambient although the intensity level of solar irradiance was not very much. This is because the more energy produces when solar light converted in the heat by stacking in the surface of solar panel which was made of glenzing material.

3.6. Normalized power output analysis

Normalized power output efficiency is the ratio of maximum output power of the photovoltaic modules calculated at outdoor condition to maximum output power of the photovoltaic modules computed at standard test conditions (STC). The normalized output power efficiency was calculated by using formula discussed earlier in equation (5) [19]. Equation (5) shows the relation of normalized power out, where ηp is normalized output power efficiency,Pmax is maximum output power at outdoor condition measured in (W) and Pmax(STC) is maximum output power at standard test conditions also measured in Watt. Normalized power output efficiency of different PV modules (thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon) were examined 50.27 %,54.03 %, 56.2 %, 47.54 % and 44.38 % respectively in overall year is shown in Figs. 8a and 8b Mono-crystalline silicon exhibit the highest normalized power output efficiency as compared to other PV modules due to quality of high solar absorptivity property, high temperature gaining property and higher value of thermal conductivity.

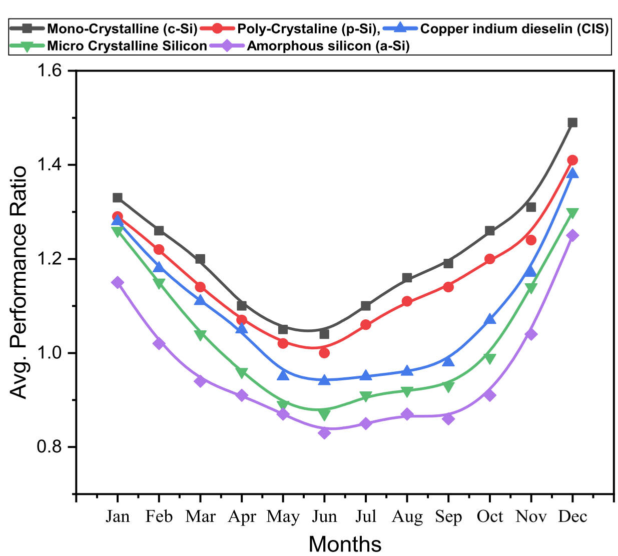

Fig. 6a Average performance values of different PV modules for whole year.

Performance analysis results data and their varying behavior are very crucial to know for prediction of best PV module in any particular weather conditions [27–30]. Comparison of all parameters of the selected modules can be examined after the optimization in Table 2 over the whole year. These operational results of all systems by analyzing and comparing their performances under the outdoor weather conditions. The results shown help to understand the operation of different PV systems to conclude the best one material under specific outdoor weather condition and also at STC standard test conditions. Normalized power output efficiency of different PV modules (mono-crystalline, polycrystalline, amorphous silicon, thin plate Copper indium diselenide, micro crystalline) were examined 56.2 %, 54.03 %, 44.38 %, 50.27 % and 47.54 % respectively in overall year. But Mono-crystalline silicon PV module proved to be distinguished due to its good solar absorptivity rate. PV module efficiency of (mono-crystalline, polycrystalline, amorphous silicon, thin plate Copper indium diselenide and micro crystalline silicone) were observed 20.8 %, 18.6 %, 5.2 %, 11.6 % and 7.7 % respectively in overall year.

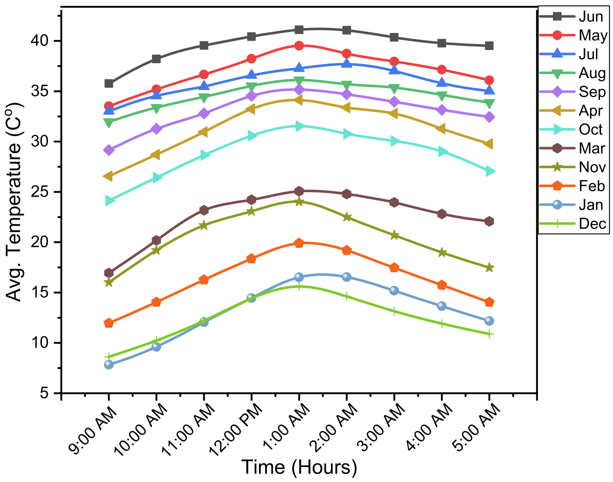

Fig. 7a Average ambient temperature of every month for the whole year from 9:00 AM to 5:00 PM.

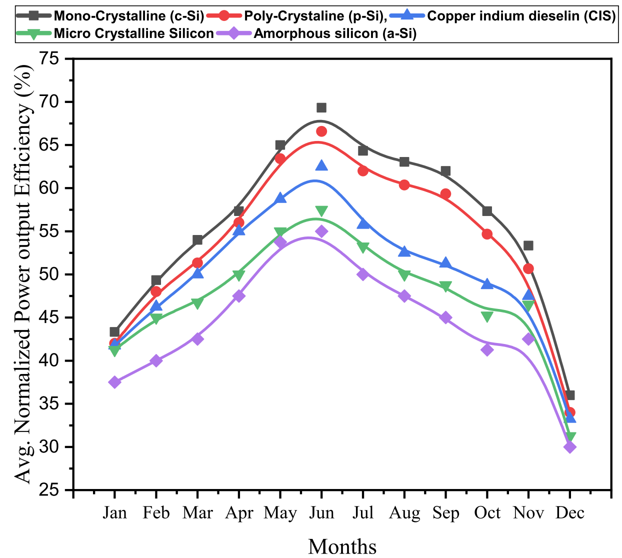

Fig. 8a Average normalized output efficiency for whole year.

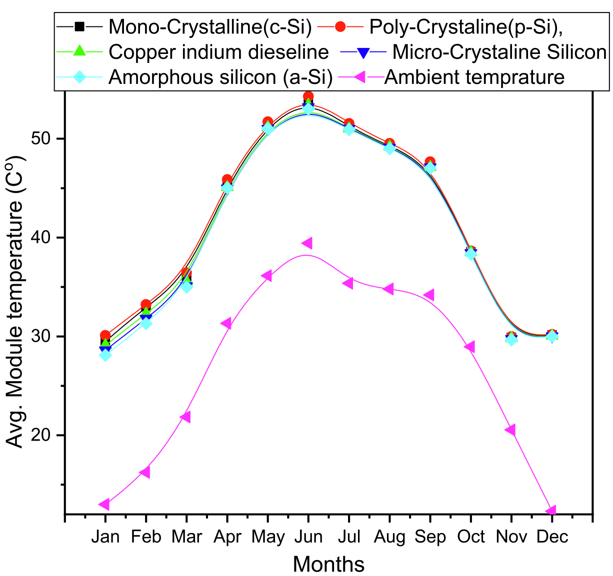

Fig. 7b Average modules temperature and ambient temperature for whole year.

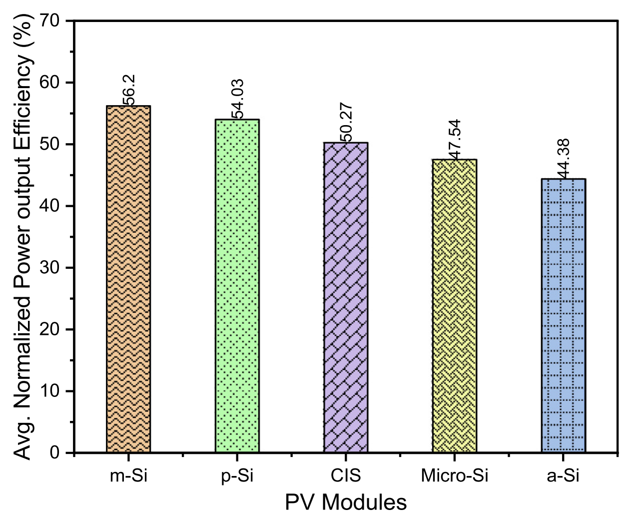

Fig. 8b Average normalized output efficiency value of different PV modules for whole year.

4. Conclusion

Solar energy capturing by PV modules technology is persuading approach for producing solar power. In this research study, the thermal performance and thermal conversion efficiency of five photovoltaic modules (thin plate Copper indium diselenide, poly-crystalline silicon, mono-crystalline silicon, micro crystalline silicone and amorphous silicon) is examined experimentally under natural sun and outdoor conditions. The contribution of irradiance absorption rate, maximum power output, module efficiency, performance ratio, module temperature and normalized power output efficiency are disclosed in the perspective of thermal performance. Experimental based outcomes described that.

Table 2 Comparison after optimization of different PV modules for whole year.

PV Modules	c-Si	p-Si	(**$CuInSn_2$**)	Micro-Si	a-Si
Maximum power output (Watt)	84/150	80.4/150	20.6/40	19.1/40	17.8/40
Module efficiency	20.8%	18.6%	11.6%	7.7%	5.2%
Performance Ratio	1.21	1.16	1.09	1.03	0.96
Normalized power output efficiency	56.2 %	54.03 %	50.27 %	47.54 %	44.38 %

- All PV modules expressed good solar energy absorption rate, higher module temperature attains, higher module efficiency, higher performance ratio and higher normalized power output efficiency.
- Average normalized power out of mono-crystalline silicon showed better result 56.2% than other modules. As before mono crystalline calculated 20.8% module efficiency and 1.21 in performance ratio.
- Mono-crystalline silicon PV module has 5% to 10% higher performance ratio (PR) and power output than others PV modules at different test conditions in this study. Compared the outcome results with the each other in this experiment study, the growing trend and order of PV modules with regard to thermal performance is mono-crystalline, poly-crystalline, thin plate Copper indium diselenide, micro crystalline silicone and amorphous silicon.
- Mono crystalline is famous for its high module efficiency and high absorptivity due to it make from thin wafers of a single silicon crystal with each silicon atom bonded with four neighboring atoms which periodic across the whole crystal. That enhance the capability of better perform in low light condition and having high PR, Mono crystalline is found to be most suitable and should be preferred in renewable energy to make it dominant with solar energy and mitigate energy import bills and the generation of CO_2 in the atmosphere.

This research duly concerns the photo thermal properties of different photovoltaic modules and applications require further research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] C. Qian, Application of low-carbon design concept of network energy consumption based on SDN architecture in high-rise residential building design, Alexandria Engineering Journal 61 (4) (2022) 3303–3312.
[2] X.u. Ping, F. Yang, H. Zhang, J. Zhang, W. Zhang, Elman and back propagation neural networks based working fluid side energy level analysis of shell-and-tube evaporator in organic Rankine cycle (ORC) system, Alexandria Engineering Journal 61 (9) (2022) 7339–7352.
[3] E.-S.-Z. El-Ashtoukhy, M.H. Abdel-Aziz, H.A. Farag, I.H. El Azab, M. Sh. Zoromba, M.M. Naim, An innovative unit for water desalination based on humidification dehumidification technique, Alexandria Engineering Journal 61 (11) (2022) 8729–8742.
[4] M. Farooq et al, Biogas up gradation for power generation applications in Pakistan. 8 (2) (2012) 107–118.
[5] M.J.R. Kamran, S.E. Reviews, Current status and future success of renewable energy in Pakistan. 82 (2018) 609–617.
[6] M.U. Khan, M. Ahmad, M. Sultan, I. Sohoo, P.C. Ghimire, A. Zahid, A. Sarwar, M. Farooq, U. Sajjad, P. Abdeshahian, M. Yousaf, Biogas Production Potential from Livestock Manure in Pakistan, Biogas Production Potential from Livestock Manure in Pakistan. 13 (12) (2021) 6751.
[7] M.H. Siddiqi, X.-M. Liu, M.A. Hussain, T. Qureshi, M. Waqas, M. Farooq, T. Iqbal, S. Nawaz, S. Nawaz, Evolution of kinetic and hydrothermal study of refused derived fuels: Thermo-gravimetric analysis, Evolution of kinetic and hydrothermal study of refused derived fuels: Thermo-gravimetric analysis. 7 (2021) 1757–1764.
[8] M.A. Shouman, A.S. Saber, M.K. Shaat, A. El-Sayed, H. Torkey, A Hybrid Machine Learning Model for Reliability Evaluation of the Reactor Protection System, Alexandria Engineering Journal 61 (9) (2022) 6797–6809.
[9] O.M. Babatunde, J.L. Munda, Y. Hamam, A comprehensive state-of-the-art survey on hybrid renewable energy system operations and planning 8 (2020) 75313–75346.
[10] O. Andreev, O. Lomakina, A. Aleksandrova, Diversification of structural and crisis risks in the energy sector of the ASEAN member countries. 35 (2021) 100655.
[11] L. Pathak, K. Shah, Renewable energy resources, policies and gaps in BRICS countries and the global impact. 13 (3) (2019) 506–521.
[12] S. Tabrizian, Technological innovation to achieve sustainable development—Renewable energy technologies diffusion in developing countries. 27 (3) (2019) 537–544.
[13] A. Qazi, F. Hussain, N.A. Rahim, G. Hardaker, D. Alghazzawi, K. Shaban, K. Haruna, Towards sustainable energy: a systematic review of renewable energy sources, technologies and public opinions. 7 (2019) 63837–63851.
[14] S. Imran, T. Korakianitis, R. Shaukat, M. Farooq, S. Condoor, S. Jayaram, Experimentally tested performance and emissions advantages of using natural-gas and hydrogen fuel mixture with diesel and rapeseed methyl ester as pilot fuels. 229 (2018) 1260–1268.
[15] M. Kashif, M.B. Awan, S. Nawaz, M. Amjad, B. Talib, M. Farooq, A.S. Nizami, M. Rehan, Untapped renewable energy potential of crop residues in Pakistan: Challenges and future directions. 256 (2020) 109924.
[16] Z. Tahir, M.J.R. Asim, S.E. Reviews, Surface measured solar radiation data and solar energy resource assessment of Pakistan: A review. 81 (2018) 2839–2861.
[17] M. Amin, D. Bernell, Power sector reform in Afghanistan: Barriers to achieving universal access to electricity. 123 (2018) 72–82.
[18] N. Chindarkar, N. Goyal, One price doesn't fit all: An examination of heterogeneity in price elasticity of residential electricity in India. 81 (2019) 765–778.
[19] W.u. He, Q. Abbas, M. Alharthi, M. Mohsin, I. Hanif, X. Vinh Vo, F. Taghizadeh-Hesary, Integration of renewable hydrogen in light-duty vehicle: nexus between energy security and low carbon emission resources. 45 (51) (2020) 27958–27968.
[20] Tariq, S., M.R. Tanweer, and U.J.G. Zafar, *Solar Energy and Its Thermal Application: A Case Study of Pakistan*. **27**: p. 29.
[21] M. Farooq, A.H. Bell, M.N. Almustapha, J.M. Andresen, Bio-methane from an-aerobic digestion using activated carbon adsorption. 46 (2017) 33–40.
[22] Z.u.R. Tahir, M. Amjad, M. Asim, M. Azhar, M. Farooq, M.J. Ali, S.U. Ahmad, G.M. Amjad, A. Hussain, Improving the accuracy of solar radiation estimation from reanalysis datasets using surface measurements. 47 (2021) 101485.
[23] M. Farooq, M. Asim, M. Imran, S. Imran, J. Ahmad, M.R. Younis, Mapping past, current and future energy research trend in Pakistan: a scientometric assessment, Scientometrics 117 (3) (2018) 1733–1753.
[24] Z.u.R. Tahir, S. Hafeez, M. Asim, M. Amjad, M. Farooq, M. Azhar, G.M. Amjad, Estimation of daily diffuse solar radiation from clearness index, sunshine duration and meteorological parameters for different climatic conditions. 47 (2021) 101544.
[25] M. Imran, H.A. Muhammad, F. Sher, M. Farooq, Y.-J. Baik, Z. Rehman, Exergoeconomic optimization of a binary geothermal

power plant, in: Thermodynamic Analysis and Optimization of Geothermal Power Plants, Elsevier, 2021, pp. 315–326.
[26] S.A. Hussnain, M. Farooq, M. Amjad, F. Riaz, Z.U.R. Tahir, M. Sultan, I. Hussain, M.A. Shakir, M.A. Qyyum, N. Han, A. Bokhari, Thermal Analysis and Energy Efficiency Improvements in Tunnel Kiln for Sustainable Environment. 9 (9) (2021) 1629.
[27] R. Ahmed, V. Sreeram, Y. Mishra, M.D. Arif, A review and evaluation of the state-of-the-art in PV solar power forecasting: Techniques and optimization. 124 (2020) 109792.
[28] S. Lindig, A. Louwen, D. Moser, M. Topic, Outdoor PV System Monitoring—Input Data Quality, Data Imputation and Filtering Approaches. 13 (19) (2020) 5099.
[29] A. Livera, M. Theristis, G. Makrides, G.E. Georghiou, Recent advances in failure diagnosis techniques based on performance data analysis for grid-connected photovoltaic systems. 133 (2019) 126–143.
[30] E. Roumpakias, A. Stamatelos, Performance analysis of a grid-connected photovoltaic park after 6 years of operation. 141 (2019) 368–378.
[31] J. Ascencio-Vásquez, K. Brecl, M. Topič, Methodology of Köppen-Geiger-Photovoltaic climate classification and implications to worldwide mapping of PV system performance. 191 (2019) 672–685.
[32] R. Madurai Elavarasan, S. Afridhis, R.R. Vijayaraghavan, U. Subramaniam, M. Nurunnabi, SWOT analysis: A framework for comprehensive evaluation of drivers and barriers for renewable energy development in significant countries. 6 (2020) 1838–1864.
[33] J. Fan, L. Wu, F. Zhang, H. Cai, X. Ma, H. Bai, Evaluation and development of empirical models for estimating daily and monthly mean daily diffuse horizontal solar radiation for different climatic regions of China. 105 (2019) 168–186.
[34] A. Shahsavari, M.J.R. Akbari, S.E. Reviews, Potential of solar energy in developing countries for reducing energy-related emissions. 90 (2018) 275–291.
[35] Z.u.R. Tahir, M. Asim, M. Azhar, G. Moeenuddin, M. Farooq, Correcting solar radiation from reanalysis and analysis datasets with systematic and seasonal variations. 25 (2021) 100933.
[36] M. Ijaz, M. Farhan, M. Farooq, G. Moeenuddin, S. Nawaz, M. E.M. Soudagar, H.M. Saqib, Q. Ali, Numerical investigation of particles characteristics on cyclone performance for sustainable environment. 39 (4) (2021) 495–503.
[37] M.A. Saeed, M. Farooq, A. Anwar, M.M. Abbas, M.E.M. Soudagar, F.A. Siddiqui, M.A. Shakir, A.-S. Nizami, I.A. Chaudhry, A. Pettinau, G.E. Andrews, H.N. Phylaktou, Flame propagation and burning characteristics of pulverized biomass for sustainable biofuel. 11 (2) (2021) 409–417.
[38] Y.K. Ramgolam, H. Shamachurn, J.Y. Coret, An In-Depth Experimental Investigation of the Outdoor Performance of Wafer and Thin Film Photovoltaics Technologies in a Tropical Climate, J. Sol. Energy Eng. 144 (3) (2022).
[39] N. Amin, C.W. Lung, K. Sopian, A practical field study of various solar cells on their performance in Malaysia. 34 (8) (2009) 1939–1946.
[40] A.J. Carr, T.L. Pryor, A comparison of the performance of different PV module types in temperate climates. 76 (1-3) (2004) 285–294.
[41] M. Bashir, H. Ali, M. Ali, A. Siddiqui, An experimental investigation of performance of photovoltaic modules in Pakistan. 19 (suppl. 2) (2015) 525–534.
[42] P. Singh, N.M. Ravindra, Temperature dependence of solar cell performance—an analysis. 101 (2012) 36–45.
[43] U. Sajjad, M. Amer, H.M. Ali, A. Dahiya, N. Abbas, Cost effective cooling of photovoltaic modules to improve efficiency. 14 (2019) 100420.
[44] T. Wongwuttanasatian, T. Sarikarin, A. Suksri, Performance enhancement of a photovoltaic module by passive cooling using phase change material in a finned container heat sink. 195 (2020) 47–53.
[45] M. Dhimish, A. Alrashidi, Photovoltaic degradation rate affected by different weather conditions: A case study based on pv systems in the uk and australia. 9 (4) (2020) 650.
[46] M. Dhimish, V. Holmes, P. Mather, M. Sibley, Novel hot spot mitigation technique to enhance photovoltaic solar panels output power performance. 179 (2018) 72–79.
[47] Jathar, L.D., et al., Effect of various factors and diverse approaches to enhance the performance of solar stills: a comprehensive review. 2021: p. 1-32.
[48] Opoku, R., et al., Experimental Investigation of Thermal Management Techniques for Improving the Efficiencies and Lcoes of Solar Pv Modules Installed in Hot-Humid Climates. Available at SSRN 4010587.
[49] Z. Li, S. Ahmed, T. Ma, Investigating the effect of radiative cooling on the operating temperature of photovoltaic modules, Solar RRL 5 (4) (2021) 2000735.
[50] Ahmad, S.A., et al., Performance Estimation of Polycrystalline Photovoltaic Module during summer.
[51] H. Ali, M. Mahmood, M. Bashir, M. Ali, A. Siddiqui, Outdoor testing of photovoltaic modules during summer in Taxila, Pakistan. 20 (1) (2016) 165–173.
[52] F. Zhang, R. de Dear, P. Hancock, Effects of moderate thermal environments on cognitive performance: A multidisciplinary review. 236 (2019) 760–777.
[53] K. Akhmad, A. Kitamura, F. Yamamoto, H. Okamoto, H. Takakura, Y. Hamakawa, Outdoor performance of amorphous silicon and polycrystalline silicon PV modules. 46 (3) (1997) 209–218.
[54] O.-M. Midtgard, T.O. Sætre, G. Yordanov, A.G. Imenes, C.L. Nge, A qualitative examination of performance and energy yield of photovoltaic modules in southern Norway. 35 (6) (2010) 1266–1274.
[55] A. Gholami, I. Khazaee, S. Eslami, M. Zandi, E. Akrami, Experimental investigation of dust deposition effects on photo-voltaic output performance. 159 (2018) 346–352.
[56] Y.N. Chanchangi, A. Ghosh, S. Sundaram, T.K. Mallick, An analytical indoor experimental study on the effect of soiling on PV, focusing on dust properties and PV surface material. 203 (2020) 46–68.
[57] K.K. Ilse, B.W. Figgis, V. Naumann, C. Hagendorf, J. Bagdahn, Fundamentals of soiling processes on photovoltaic modules. 98 (2018) 239–254.
[58] S.A. Sulaiman et al, Effects of Dust on the Performance of PV Panels. 2011 (58) (2011) 588–593.
[59] M. Zain, M. Amjad, M. Farooq, Z. Anwar, R. Shoukat, E.P. Bandarra Filho, X. Du, Performance investigation of a solar thermal collector based on nanostructured energy materials. 7 (2021).
[60] N. Hariri, A novel dust mitigation technology solution of a self-cleaning method for a PV module capable of harnessing reject heat using shape memory alloy, Case Studies Therm. Eng. 32 (2022) 101894.
[61] D.I. Paul, Dust Deposition on Photovoltaic Modules: Its Effects on Performance, in: The Effects of Dust and Heat on Photovoltaic Modules: Impacts and Solutions, Springer, 2022, pp. 3–46.
[62] M. Abderrezek, M. Fathi, Experimental study of the dust effect on photovoltaic panels' energy yield. 142 (2017) 308–320.
[63] S. Kichou, S. Silvestre, G. Nofuentes, M. Torres-Ramírez, A. Chouder, D. Guasch, Characterization of degradation and evaluation of model parameters of amorphous silicon photovoltaic modules under outdoor long term exposure. 96 (2016) 231–241.
[64] C. Madumelu, B. Wright, A. Soeriyadi, M. Wright, D. Chen, B. Hoex, B. Hallam, Investigation of light-induced degradation in

N-Type silicon heterojunction solar cells during illuminated annealing at elevated temperatures. 218 (2020) 110752.

[65] Rosyid, O.A. Comparative performance testing of photovoltaic modules in tropical climates of Indonesia. in AIP Conference Proceedings. 2016. AIP Publishing LLC.

[66] A. Sattar, M. Farooq, M. Amjad, M.A. Saeed, S. Nawaz, M.A. Mujtaba, S. Anwar, A.M. El-Sherbeeny, M.E.M. Soudagar, E. P. Bandarra Filho, Q. Ali, M. Imran, A. Pettinau, Performance Evaluation of a Direct Absorption Collector for Solar Thermal Energy Conversion. 13 (18) (2020) 4956.

[67] N. Mukisa, R. Zamora, Optimal tilt angle for solar photovoltaic modules on pitched rooftops: A case of low latitude equatorial region, Sustainable Energy Technol. Assess. 50 (2022) 101821.

[68] Khanna, S., K. Reddy, and T.K.J.I.J.o.T.S. Mallick, Optimization of finned solar photovoltaic phase change material (finned pv pcm) system. 2018. **130**: p. 313-322.

[69] Kafui, A.D., I. Seres, and I.J.A.T.A. Farkas, Efficiency comparison of different photovoltaic modules. 2019. **22**(1): p. 5-11.

[70] E. Elibol, Ö.T. Özmen, N. Tutkun, O. Köysal, Outdoor performance analysis of different PV panel types. 67 (2017) 651–661.

[71] A.A. Hachicha, I. Al-Sawafta, Z. Said, Impact of dust on the performance of solar photovoltaic (PV) systems under United Arab Emirates weather conditions. 141 (2019) 287–297.

[72] D.H. Daher, L. Gaillard, M. Amara, C. Ménézo, Impact of tropical desert maritime climate on the performance of a PV grid-connected power plant. 125 (2018) 729–737.

[73] Louwen, A., et al., Comprehensive characterisation and analysis of PV module performance under real operating conditions. 2017. **25**(3): p. 218-232.

[74] A. Sohani, H. Sayyaadi, Providing an accurate method for obtaining the efficiency of a photovoltaic solar module. 156 (2020) 395–406.

[75] D.A. Quansah, M.S. Adaramola, Assessment of early degradation and performance loss in five co-located solar photovoltaic module technologies installed in Ghana using performance ratio time-series regression. 131 (2019) 900–910.

[76] A. Hasan, J. Sarwar, H. Alnoman, S. Abdelbaqi, Yearly energy performance of a photovoltaic-phase change material (PV-PCM) system in hot climate. 146 (2017) 417–429.